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# An Interval Training Bout on Cognitive Performance in Healthy Adults

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AN INTERVAL TRAINING BOUT ON COGNITIVE PERFORMANCE IN HEALTHY  
ADULTS

by

David Young

Under the Direction of Jim McMillan

Abstract

Cognitive performance has been shown to improve with regular aerobic exercise training. Despite this, most Americans do not adhere to current exercise prescription guidelines. High intensity interval training (HIIT) has been suggested as a lower time commitment, more enjoyable alternative to regular aerobic exercise. Twenty nine apparently healthy college-aged adults were recruited and administered a high intensity interval training session with a pre- and 24 hours-post-exercise cognitive performance test. No changes were found in performance following the bout of high intensity interval training. No significant interactions were observed when comparing performance to gender, training age, training goal, or intra-exercise rating of perceived exertion (RPE). More study is needed to assess the efficacy of a long term HIIT intervention on cognitive performance changes using more sensitive testing procedures.

INDEX WORDS: High intensity interval training, Cognitive performance, Exercise psychology, Acute effects of exercise

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ADULTS

by

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AN INTERVAL TRAINING BOUT ON COGNITIVE PERFORMANCE IN HEALTHY  
ADULTS

by

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Electronic Version Approved:

Spring 2014

## DEDICATION

I dedicate this to my loving parents and wife, who always support me. As well as Craig “Bullet” Still. RIP buddy.

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Table 1- Demographics Data

Variable	All (19)	Males (12)	Females (7)
Age (y)	21±1.9	21±1	22±2.8
Academic Year (y)	3.11±1.1	3.42±.86	2.14±1.46
Height (cm)	173.58±8.486	178.42±5.34	165.3±6.13
Weight (kg)	79.326±14.684	84.58±14.39	70.31±10.08
Body fat Percentage (%)	19.89±8.42	15.22±5.28	27.899±6.574
Fat Free Mass (kg)	64.04±11.93	71.12±8.84	51.904±4.378
Training Age (y)	2.558±2.027	2.883±2.209	2±1.512

Demographics Data. BF and FFM by skinfold. Training by self-report

Table 2- Rating of perceived exertion

Rating of Perceived Exertion by Goal and Training Status (Borg Scale)	
<b>Training Goal</b>	
Strength/Power	16.16±1.6
Aesthetics	17.25±1.7
Endurance	16±1
Team Sports	16±1.79
<b>Training Age</b>	
Over 2 years	15.8±1.32

RPE recorded after interval number 5

Table 3- Montreal Cognitive Assessment Subscales

Test (Maximum)	Score Pre-Exercise	Score Post-Exercise	P=
MoCA (30)	27±1.856	26.632±1.892	0.46
Executive Control (5)	4.68±.582	4.526±.697	0.38
Naming (3)	2.947±.229	2.895±.315	0.58
Attention (6)	5.579±.607	5.421±.8377	0.55
Language (3)	2.684±4.776	2.421±.607	0.1
Abstraction (2)	1.26±.7723	1.73±.4524	0.33
Delayed Recall (5)	3.684±.946	3.79±1.182	0.73
Orientation (6)	5.895±.315	5.842±.375	0.58

MoCA Scores. Paired Samples Test

Table 4- Effects of Training age and Gender on MoCA

Training Age	MoCA 1	MoCA 2	Between Groups P=
Under 2 Years	27±1.41	26.56±1.67	0.888
Over 2 Years	27±2.26	26.7±2.16	
<b>Gender</b>			
Male	27±1.95	26.83±1.99	0.605
Female	27±1.83	26.29±1.79	

Determined by 2-way ANOVA

## Introduction

Both acute exercise and regular exercise training have a number of effects on the brain. Overall, long term aerobic and resistance training have shown promising results in the maintenance and improvement of cognitive performance in a variety of populations. These effects have been observed in large scale public health studies and have led scientists to become increasingly inclined to investigate this relationship in detail throughout the past two decades (1). The majority of studies have been performed with sustained moderate cardiorespiratory exercise. These studies have been fairly consistent in suggesting that a regular aerobic exercise training regimen can increase cognitive performance in some populations, as well as delay or prevent cognitive decline with aging (2). More recently, similar effects have been observed in resistance training (3).

The underlying mechanisms relating long term exercise training and cognitive performance are predominately physiology based. Brain derived neurotrophic factor (BDNF) is crucial to cognition and is modulated by exercise (4). Brain derived neurotrophic factor is produced in several areas including skeletal muscle (5). Conversely insulin resistance, which is often associated with a sedentary lifestyle, has been shown to correlate with atrophy in the hippocampus, which corresponds with inability to properly form new long term memories, as well as reduced functional connectivity within the brain (6-8). BDNF has been shown to increase insulin sensitivity (9).

The impact of single bouts of exercise on cognitive performance has also been documented in aerobic exercise, resistance exercise, and alternative exercise techniques such as

yoga (10-11). The mechanisms driving the effects of acute exercise are distinct from those relating to regular exercise training. Typically, change in cognitive performance as a result of acute exercise is believed to be caused by primarily psychological mechanisms such as increased peripheral sensitivity to motor input, as well as increased sensitivity to sensory stimuli (12). Other mechanisms are more physiology based; including increased total blood flow throughout the body, increased epinephrine and norepinephrine levels and their effects on memory consolidation (13).

## **Literature Review**

### **Mechanisms Associated With Cognitive Benefits from Exercise**

Ratey and Loehr (2011) recently categorized the proposed mechanisms responsible for short term cognitive changes from acute exercise. In their review, they suggested three categories of important mechanisms of action that acute exercise may have on cognitive performance. These mechanisms included molecular systems, cellular systems and psychological systems. The molecular systems included insulin function within the brain, catecholamines like epinephrine and norepinephrine, and neurotrophins like brain derived neurotrophic factor (BDNF). The cellular systems included changes to synaptic plasticity, neurogenesis, and angiogenesis. The psychological system mechanisms included attention, learning, and memory (14).

In the molecular level mechanism, improved insulin sensitivity is a major outcome of high intensity interval training (15). A high normal fasting plasma glucose value, an indicator of potential insulin dysfunction, has been linked to atrophy in the hippocampus and amygdala, and to neurodegeneration, seen as early as ages 60-64 (6). This atrophy may decrease ability to effectively encode new memories (8). Type 2 diabetics have been shown to have altered functional connectivity in their default mode network, as measured by functional magnetic resonance imaging (fMRI). This network includes the posterior cingulate cortex and is directly related to cognition. The authors suggested that, using *fMRI*, it was determined that several brain regions were not as strongly connected to the posterior cingulate cortex in type 2-diabetics

when compared to non-diabetic controls (7). This decreased connectivity can be apparent via fMRI before any noticeable cognitive dysfunction or decrease in hippocampal volume (7).

Stress and arousal hormones are important effectors of memory consolidation and cognition (13). Cahill and Alkire (2003) investigated the injection of epinephrine into healthy young male adults. These authors found that an injection of epinephrine aided males in retrograde memory consolidation. Males who were provided information and then injected with epinephrine were later better able to recall this information when given a retention test.

Brain derived neurotrophic factor (BDNF) is critical in the maintenance of neurosynapses and neuroplasticity, and its deficiency has led to insulin dysfunction and obesity in mice (16-17). In a human case study, a BDNF deficient adolescent developed insulin and leptin resistance and his resulting body mass index (BMI) was 3.8 standard deviations above the age-related mean (18). These authors suggested the adolescent's obesity, insulin resistance, and leptin resistance was a result of his BDNF deficiency (18).

Goda et al. (2013) investigated the effects of single bout of moderate intensity aerobic exercise on serum BDNF. These researchers found that about half of the subjects had a noticeable rise in serum BDNF post-exercise, yet when measured as a group, the changes were not significant (19). Ferris, Williams, and Shen (2007) found that exercise intensity was a modulator for changes in serum BDNF post exercise. These authors reported that either a VO2-MAX graded exercise test (GXT) or a 30 minute bout of exercise above the lactate threshold increased post-workout BDNF. In contrast, exercising 10% below the lactate threshold did not increase BDNF (20). While this effect appears to be short lived, and may only be apparent for hours after exercise has been ceased, regular exercise training may facilitate improvements in



BDNF response to exercise (20-21). Berchtold et al. reported that sedentary rodents which had been physical active previously were more sensitive to an exercise induced BDNF response when exercise was reintroduced compared to rodents that spent their entire lives sedentary (21). Individuals with disabilities that typically result in decreased BDNF may also have similar benefit from exercise (22). Intense strength training has yielded promising results with regards to elevating serum BDNF levels (4). Given the current research, it is likely that high intensity interval training may increase serum BDNF levels in human subjects.

When looking at long term exercise training, the underlying mechanisms for cognitive improvement represent more permanent changes. In mice studies, BDNF expression over time was elevated with exercise training. These results were typically maintained until cessation of the exercise protocol and for a few weeks of sedentary behavior (23). According to the authors, the changes were most notable in younger mice (23). In rats, daily exercise had a protective effect on brain BDNF levels during periods of sedentary behavior, BDNF did not return to baseline until after seven straight days of sedentary behavior (21). The benefit of exercise on BDNF in rodents diminishes over time, however (24).

Within the cellular level system, long term exercise training and fitness may also have an effect on brain structure. Using magnetic resonance imaging (MRI) and measuring the volume of the basal ganglia, Chaddock et al. (2010) found that pre-adolescent children with above average cardiorespiratory fitness had greater dorsal striatum volume, which is associated with executive function and motor control, compared to less fit children. Fit children also scored higher on cognitive performance tests, especially relating to attention (25). Exercise training has even been shown in adults to prevent age-related atrophy in grey matter (26).

Unlike long term regular exercise training, a single bout of exercise is unlikely to produce detectable structural changes in the central nervous system. The majority of physiological changes observed from a single bout of exercise are related to changes in peripheral blood flow that occur during and after exercise, which has been noted in the target action of high intensity interval training (27).

Within the psychological systems, there is evidence to suggest that acute exercise changes an individual's strategy in decision making. The reticular-activating hypofrontality model developed by Dietrich (2003) explains that during and immediately after exercise the reticular-activating system of the brain modulates activity and facilitates faster, more efficient information processing and hinders the actions of the prefrontal cortex. Together these effects will minimize time latency and explicit cognitive energy expenditure (28-29), which will increase efficiency of cognitive resource utilization and allow for greater priority to be placed on motor function in high stress situations as an evolutionary adaptation. These adaptations will, for the short term, decrease prefrontal-dependent cognition (30). In their investigation, Dietrich and Sparling exercised a group of young males using either a cycling or running protocol designed to elicit a response of 80-90% of age-based maximum heart rate and sustained this level for 45 minutes. When compared to a control group with no exercise, the experimental condition revealed a deleterious effect on higher level thinking relative to their pre-exercise baseline. These results were not found in tests that ignored higher level thinking, lending support to the reticular-activating hypofrontality model (32). One possible mechanism for this phenomenon is competition within the brain for oxygen and blood flow. During intense exercise, such as the 150% of VO<sub>2</sub>-MAX during interval training employed by Shibuya and colleagues, a decreased blood flow to the cerebral cortex was found (31). A decreased blood flow to the cerebral cortex

was also found with intense isometric muscular contractions (32). Decreased blood flow to the cerebral cortex may lead to unintentional strategizing towards increasing efficiency.

## **Cognitive Performance Outcomes from Exercise**

### **Aerobic Exercise and Training**

Aerobic exercise is a continuous locomotive movement sufficient to increase heart rate and oxygen consumption, usually sustained for thirty minutes or more (33). The intensity of an aerobic exercise training program is usually measured in a percentage of VO<sub>2</sub>-MAX, age predicted heart rate max, or workload in watts (33). In his 2010 review paper, Best explained how data suggests aerobic physical activity facilitates problem solving skills and executive function in children (34). Aerobic activity is cognitively engaging, and leads children to unknowingly acquire motor skills and adopt strategies such as pacing. Aerobic physical activity that is organized as play also yields benefits from a socialization standpoint (34). A positive relationship between exercise and cognition is seen in healthy populations as well as special populations, such as depressed individuals (35). Improvements can be seen in the executive function of middle aged women after exercise bouts of either aerobic or resistance training (10).

Acute aerobic exercise also has direct cognitive consequences. When studying young men and women, cycling led subjects to alter only certain aspects of information processing via a cognitive performance test. For example, mean reaction time improved during exercise, but error rate was not affected (36). Reaction time improvements may be explained by increased sensitivity of the neuromuscular system to input and improved speeds of muscle contraction when selecting responses during exercise (37). This improvement, however, is still apparent when speed of the movement is taken out of the equation, because acute exercise improves

premotor reaction time (38). Generally, a moderate bout of aerobic exercise, such as 20 minutes of walking at 60% of the age-predicted heart rate reserve (HRR) does have a short term positive benefit on lower level information processing such as pre-motor reaction time (36). There is little or no evidence to suggest a short term improvement on higher level thinking, however (39). While components like reaction time and other lower level processes are typically improved with an acute bout of aerobic training, higher level functions are typically left unchanged or even hindered, if the exercise is sufficiently intense (17). In their meta-analysis, of 79 articles, Chang et al. (2012) suggested that twenty minutes after cessation of exercise, overall cognitive performance was improved. Prior to that, and depending on intensity, performance may be hindered due to the physical recovery process (31). Because the majority of these effects subside soon after exercise is ceased, long term negative consequences of exercise on cognitive performance are unlikely.

When researching college aged men and women, Arcelin et al. (1998) tested students' reaction times before and during a bout of aerobic exercise. During exercise, reaction times were improved. The authors attributed this to late stage motor processes, which correspond to speed of transmission from central structures to the periphery, and may be related to exercise based increases in arousal (36). These effects can also be seen in middle aged and older individuals (39). It is important to note that pre-motor reaction time and reaction time are distinct processes, as pre-motor reaction time excludes the time elapsed between the initiation of and completion of movement. Therefore, the improvements to reaction time from exercise cannot be regarded as only a movement outcome (40).

Acute bouts of intense aerobic exercise also impact the effort produced during cognitive tasks administered while exercising. Vigorous aerobic training of 35 minutes at 90% of the ventilator threshold was more likely to cause individuals to cascade numbers in observable and obvious patterns when asked to list numbers randomly, instead of truly random listing, suggesting a more efficient and less effortful approach (41). There are physiological reasons that may explain the decrease in executive function seen in intense exercise. Bhambhani, Malik, and Mookerjee (2007) investigated the respiratory compensation threshold, analogous to the lactate threshold, and cerebral oxygen concentrations associated with intense exercise. They found that once the respiratory compensation threshold was passed, concentration of oxygen in the pre-frontal cortex was reduced, due to competing resources partially from the primary motor cortex (42). Due to the transient deleterious effect that very intense aerobic exercise has on oxygen concentration and blood flow to the cerebral cortex, scientists may expect a similar phenomenon to occur with high intensity interval training. These effects typically persist for less than an hour (42).

Measuring cognitive performance directly has led to promising results with regards to aerobic training. In school aged children, aerobic physical activity interventions have shown improvements on executive function, and children who engage in more physical activity are likely to have better school and cognitive performance (34). Several studies have suggested that aerobic exercise training is effective at improving most aspects of cognitive performance, however, data concerning the effects of aerobic exercise and working memory is inconsistent (43). Studies have also shown that aerobic exercise training helps to prevent gray matter atrophy (26). Despite these known benefits associated with regular aerobic exercise training, most Americans do not adhere to exercise training guidelines (44). The most commonly cited reason

is lack of time. The current recommendation is 150 minutes a week (44). This adherence issue has been suggested to be alleviated by high intensity interval training (44).

### **High Intensity Interval Training**

High intensity interval training (HIIT) is the act of completing repeated bursts of vigorous activity interspersed with periods of rest, active rest, or lighter activity (45). HIIT is often recommended as a lower time commitment, more enjoyable alternative to continuous moderate aerobic activity. Despite a higher rating of perceived exertion recorded by their college aged participants, Bartlett et al. (2011) found using the physical activity enjoyment scale that HIIT, when performed with three minute intervals at 90% of VO<sub>2</sub>-MAX and three minutes of rest, was better enjoyed than a bout of continuous exercise at 70% of VO<sub>2</sub>-MAX for 50 minutes (46). The authors suggested that increasing exercise enjoyment will increase adherence (46). In their review, Bird and Hawley explained that due to lower time commitment, high intensity interval training may lead to greater exercise adherence than continuous aerobic exercise (44). Despite the name and higher typical ratings of perceived exertion, HIIT is well tolerated even amongst coronary heart disease patients (47).

At the physiological level, repeated Wingate tests have been shown to significantly improve insulin sensitivity in young males as well (48). In their investigation, as little as 250kcal of work was sufficient to improve insulin activity as measured with an oral glucose tolerance test. Subjects performed between four and six repeated Wingate tests with four minutes of rest in between efforts, and repeated this protocol six times over two weeks. While each session lasted only 17 to 26 minutes, the intervention was sufficient to improve insulin action (49). Similar results have been found in interval training at 80-90% of VO<sub>2</sub>-MAX in college aged

women. Insulin sensitivity scores improved to a greater degree than the group which completed a training regimen of continuous aerobic exercise (50). Other testing protocols that have been investigated suggested that both sprint interval and more aerobic interval training have elicited improved insulin sensitivity (51). Given the relationship between insulin resistance and cognitive dysfunctions, the hypothesis of a beneficial relationship between HIIT and cognition appears promising (52). No evidence is available about the specific impact of high intensity interval training at the cellular level.

At the psychological level, few studies have been completed using a HIIT protocol and measuring cognitive performance. Still, inferences can be made regarding HIIT's impact on the same mechanisms outlined by Ratey and Loehr (2011). At the molecular level, high intensity interval training above the lactate threshold may increase BDNF, based on results from aerobic exercise studies conducted above the lactate threshold (20). High intensity interval training also causes a catecholamine response. Trapp, Chisholm, and Boutcher (2007) studied the effects of very short duration high intensity interval training, with bouts of 8-24 seconds in women. Subjects used 70% of their VO<sub>2</sub>-PEAK value during intense intervals, which were interspersed with intervals of 30 watts. This HIIT protocol caused an increased output of catecholamines epinephrine and norepinephrine (49). Given the evidence suggesting that catecholamines are facilitative in the encoding of long term memories, these results gives promise to the notion of high intensity interval training as a method to improve some aspects of cognitive performance (13). Similar changes have been found using Wingate tests, a measure of anaerobic power and fatigue commonly used in exercise physiology labs, in college aged men and women (53).

Based on the consistency of the positive literature to suggest aerobic exercise is beneficial to cognitive performance (2), as well as the similar outcomes that HIIT has produced with regards to many physiological variables that have been shown to correlate with cognitive performance, there is foundation to hypothesize that high intensity interval training may have similar outcomes with cognitive performance (27;49;51;54).

The purpose of this study was to examine the impact of a single high intensity interval exercise bout on cognitive performance in healthy college aged men and women.



## Methods

### Subjects

Twenty nine apparently healthy men and women ranging from 18-26 years of age were recruited from the staff and students of a public university in the Southeastern United States. Subjects were recruited through word of mouth, e-mail, and classroom recruitment. Subjects received no monetary compensation for their participation. The research protocol was approved by the Institutional Review Board (IRB), and all subjects gave their written consent for participation. Subjects were also informed of their ability to cease participation at any time.

Subjects were instructed to abstain from exercise for 36 hours prior to their initial session. Subjects were also instructed to maintain normal routines as best as possible, especially when concerning food intake, hydration, and caffeine consumption. During their first session, subjects were interviewed and assessed for inclusion and exclusion criteria. Subjects who were unable to exercise, as well as those who had been diagnosed with a psychological or neurological disorder that impacted cognition were removed from the data analysis. Upon signing the informed consent form, subjects were given a demographic and training history form which was filled out with the assistance of an investigator. Subjects provided their age, student status, academic year, height, and weight, as well as a brief training history which included their training age and primary goals with exercise. Their options for primary goals were strength/power, aesthetics, endurance athletics, or team sports. Next, body composition (BF%) was measured using a three site skinfold analysis. Males were assessed on their chest, abdomen, and thigh. Females were assessed on their triceps, suprailliac crest, and thigh. Measurements were taken from the right side of the body, and rotated through the three sites. Each site was

measured at least twice, including a third measurement if the first two were different beyond 2%. The sum of the measurement sites were used to calculate body composition and then converted to bodyfat percentage (56-57). Following their body composition testing, subjects were given the Montreal Cognitive Assessment (MoCA) by an investigator trained in psychometrics.

Seven to fourteen days later, subjects returned for their training session. Subjects were instructed to abstain from exercise the day of the session, and continue abstaining until after their second cognitive performance test. Subjects were also instructed to maintain normal eating, hydration, and caffeinating patterns. Subjects filled out a Par-Q form to ensure they were healthy enough to exercise. Next, subjects were weighed with shoes on and this weight was used to calculate resistance in watts, which was calculated as 85% of that which would be used for a Wingate test. This value was first pilot tested using a male and female volunteer. The protocol was well tolerated and elicited an end-of-exercise rating of perceived exertion (RPE) of 16 for both subjects. Subjects were given constructions concerning the protocol and were guided during the 5 bouts of high intensity interval training. Constant encouragement was provided. Rating of perceived exertion (RPE) using the Borg scale was collected at the end of the third and fifth intervals. After the session, subjects were monitored in the lab for at least ten minutes to ensure recovery from their exercise and were provided with a carbohydrate and electrolyte containing beverage.

The following day, subjects returned for their second cognitive performance test. Subjects were instructed to maintain normal eating, hydrating, and caffeinating patterns prior to the training session. Subjects filled out an alternative version of the Montreal Cognitive Assessment. Upon completion of the test, subjects were finished with their participation duties.

## **Cognitive Performance Tests**

One of three forms of the Montreal Cognitive Assessment (MoCA) was delivered to all subjects by an investigator trained in psychometrics. The MoCA was designed to detect mild cognitive impairment (MCI). The Montreal Cognitive Assessment was chosen because it offered a time efficient and simple to administer tool that could be performed with basic training for a large number of subjects. The test also has three versions, allowing investigators to test subject's pre and post-exercise scores without issues arising from learning or memorization of the test. Test-retest reliability for the MoCA has been reported with an inter class correlation of .79 in patients with Parkinson's disease (95% confidence intervals) (58). Testing was conducted in a quiet room. Each test was performed with a pen and paper and required approximately ten minutes to administer. Scores can range from a minimum of zero and a maximum of thirty and were scored by the trained administrator. The average score on the MoCA is 27.4 with a standard deviation of 2.2 (61;67). The MoCA contains an overall score, as well as subscales for executive control, naming, attention, language, abstraction, delayed recall and orientation. Each subject was given a different version of the test in their second trial in order to eliminate any memorization or learning effect. As all subjects were native English speakers, the test was administered in English.

## **High Intensity Interval Training Session**

Subjects arrived at the Human Performance lab for their training session. Instructions were provided to hydrate well, eat normally and wear athletic clothing for their training session. Upon completion of the Par-Q, subjects were weighed with their shoes on. This weight was used to calculate their resistance during the training session. Resistance was set to 85% of that which

would be used for a Wingate test in order to allow subjects to complete five intervals of 60 seconds, instead of the one interval of 30 seconds used in the Wingate. The formula used was  $((.075 * \text{weight (KG)}) * 25) * .85$ . The standard Wingate formula calls for use of 7.5% of the subject's weight to be used (60). In order to convert the resistance from kilogram-force to watts, we multiplied the original value by 25. This was necessary to program the Corval Lode Cycle Ergometer. Finally, we took 85% of this to achieve the final resistance. This formula was chosen to avoid the need for an aerobic fitness VO2-MAX test. Excluding the aerobic fitness test was down for practical reasons, eliminating an unnecessary testing session. This protocol was also chosen as a way to avoid continuous aerobic exercise, as has been suggested as poorly adhered to and enjoyed (44). Subjects were then placed on the Lode Corval Cycle Ergometer and instructed to become familiar with the ergometer as well as adjust the handlebars and seat as needed. The exercise protocol was programmed into software included with the Parvo Metabolic Cart which was used to control the cycle ergometer. The interval training session consisted of five rounds of maximal effort against the weight-based resistance for 60 seconds interspersed with 5 rounds of active rest with 25 watts resistance. The protocol was as follows: A 3 minute warm up with 25 watts of resistance at a self-selected pace. At the culmination of their warm up, wattage automatically increased in a step fashion to the prescribed level and subjects were instructed to pedal at maximum effort for sixty seconds. Subsequently, during the last five seconds of each active rest interval, subjects were instructed to accelerate to maximum speed. This allowed for maximal work potential during the intense intervals and decreased the need to accelerate against higher resistance. Each of the five intense 60 second rounds was interspersed with a round of sixty seconds at a resistance of 25 watts at a self-selected pace for active recovery. After the fifth interval, subjects remained on the cycle for a two minute cool down

pedaling at 25 watts of resistance. Throughout each of the intense intervals, encouragement was consistently given. Throughout each of the recovery intervals, water and paper towels for sweat were provided by the investigators. After the two minute cool down, subjects were monitored for at least ten minutes to ensure recovery and given encouragement to consume their sports beverage.

### **Statistical Analysis**

Data were analyzed using descriptive statistics (Mean  $\pm$  SD), dependent T-tests and two way-ANOVA. Changes in cognitive performance were determined by analyzing pre- and post-exercise values. All analyses were performed on an IBM compatible computer using SPSS (version 21.0, SPSS Inc., Chicago, Ill). For all the analyses, a probability level of  $p=0.05$  was chosen to indicate statistical significance.

## Results

The final data analysis included 19 subjects. Twenty nine subjects were recruited, one was used for pilot data, one was removed due to diagnosis of attention deficit hyperactivity disorder, and 8 people were removed after failing to attend all three sessions. Full descriptive data can be seen in Table 1. Six participants each identified their main goals as either strength/power or team sports. Four subjects were primarily focused on aesthetics and three identified endurance as their primary goal. Across all subjects, the average Borg Rating of Perceived Exertion (RPE) after the fifth interval was  $16.3 \pm 1.57$  with a minimum of 13 and a maximum of 19. For most categories, body composition did not modulate rating of perceived exertion. Males over 18.5 percent bodyfat, however, reported significantly higher ratings of perceived exertion than males of lower bodyfat percentages ( $p=.006$ ). A higher score indicates males over 18.5% bodyfat found the training bout more difficult than females and males with lower bodyfat levels. Complete RPE analysis can be found in Table 2.

On the 30 point scale, subjects' average scores were  $27 \pm 1.856$  on the first MoCA, and  $26.632 \pm 1.892$  on the second test ( $p=0.463$ ). Higher scores on the Montreal Cognitive Assessment indicate increased performance. There were no significant differences observed in any subscale of the test between the pre- and post-exercise conditions. There was however a slight downward trend observed in most of the subscales. Executive control scores decreased from  $4.68 \pm .58$  to  $4.53 \pm .69$  ( $P=0.38$ ). Naming decreased from  $2.95 \pm .23$  to  $2.89 \pm .32$  ( $P=0.58$ ). Attention decreased from  $5.58 \pm .61$  to  $5.42 \pm .84$  ( $P=0.55$ ). Language decreased from  $2.68 \pm .478$  to  $2.42 \pm .60$  ( $P=0.09$ ). Orientation decreased from  $5.89 \pm .32$  to  $5.84 \pm .36$  ( $P=0.58$ ). Two subtests did

notice slight increases. Abstraction increased from  $1.26 \pm .77$  to  $1.73 \pm .45$  ( $P=0.33$ ). Delayed recall increased from  $3.68 \pm .95$  to  $3.79 \pm .38$  ( $P=0.73$ ). A breakdown of the subtests can be seen in Table 3.

No significant interactions were found comparing the MoCA score changes in regards to gender ( $p=.605$ ). Likewise, no significant interaction was found when comparing the MoCA score changes to training age ( $p=.888$ ). Participants who had been training for under two years scored an average of  $27 \pm 1.41$  on the first MoCA, and  $26.56 \pm 1.67$  on the second. Subjects who reported training for over two years scored  $27 \pm 2.26$  and  $26.7 \pm 2.16$ , respectively. Males averaged  $26.93 \pm 1.89$  on the first MoCA, and  $26.85 \pm 1.90$  on the second. Females averaged  $27.17 \pm 1.94$  on the first MoCA, and  $26.17 \pm 1.94$  on the second.

## Discussion

This is among the first investigations examining the relationship between high intensity interval training and cognitive performance. In this study, a bout of HIIT had no significant impact on cognitive performance when measured approximately 24 hours afterwards. Deleterious effects on higher level function brought on by intense exercise are typically less than one hour in duration, so the slight but non-significant downward trend being apparent 24 hours after exercise is most likely just variation (12). The hypofrontality model cannot explain our results, as pre-frontal cognition inhibition also does not persist for 24 hours (28). Each subscale of the MoCA measures pre-frontal dependent cognition, so improvements to lower level function, such as reaction time, which are also short lived, are not measured by the Montreal Cognitive Assessment (40;59). The Montreal Cognitive Assessment is used primarily as a screening tool for Mild Cognitive Impairment (59;61). This may indicate that the test is not sufficiently sensitive to track changes in cognitive function in healthy, younger adults after a single session of exercise. Other experiments investigating the impact of physical activity on performance in the Montreal Cognitive Assessment have indeed been employed mostly on older adults (66).

In contrast with previous data, no gender differences between scores on the MoCA were found. Mittal et al., used the Montreal Cognitive Assessment to examine the relationship between gender and cognitive functions in college-aged men and women in India. Their results indicated that females significantly outperformed males on the test; however results of the present study released no such pattern. Mittal et al., did have a larger sample size, which may



explain their ability to establish significance (67). The overall scores achieved in this study roughly correlate with established norms as well as Mittal et al (61;67).

Exercise intensity does modulate the short term changes in cognitive function in resistance training (62). In this investigation, the researchers found that working at 80% of heart rate reserve caused a decline in executive function greater than groups working at 30 or 50% of heart rate reserve. The ratings of perceived exertion recorded in this experiment coordinate roughly with previously set standards of RPE that elicit 80-85% of heart rate reserve (63). Regardless, the dose of exercise administered did not create a decline in executive function when measured 24 hours after exercise.

Measuring cognitive performance 24 hours after exercise is less common when performing a single bout than immediately or after a one hour delay. This was chosen because of the physiological recovery to exercise. However, some physiological changes, such as insulin function, remain apparent for at least 24 hours after exercising (64). After an acute bout of exercise, BDNF was found to require 24 hours to increase above baseline levels in mice. When measured immediately after exercise, as well as six hours after exercise, researchers found no change in BDNF. This increase remained apparent at 48 hours, but levels returned to baseline after 72 hours (65). This led us to choose a testing point of 24 hours post-exercise in order to investigate a possible relationship between known physiological effects and possible cognitive effects. No blood values were measured during this investigation, so the impact of HIIT on BDNF 24 hours post-exercise is still unstudied.

High intensity interval training has a positive impact on several of the physiological variables associated with cognitive performance, including epinephrine release, and insulin

function (48). It is apparent in aerobic training studies that these physiological mechanisms take time to influence actual cognitive performance (2). Acute bouts of aerobic exercise rarely yield any significant change after a 20 minute or longer rest period (12). It is possible that a long term high intensity interval training intervention would yield similar result to that of aerobic or resistance exercise. Given that there is evidence to suggest that HIIT may improve exercise adherence (44), more studies looking into the relationship between regular HIIT and cognition are needed. Given the impact that an acute bout of exercise has on increasing epinephrine levels (50) it is possible there is a beneficial relationship between acute exercise and cognitive performance on tests that measure memory (13). As it is apparent that acute bouts of exercise need to be performed above the lactate threshold to stimulate a BDNF response, and most high intensity interval training is done above the lactate threshold, researchers may expect to see post-exercise increases in BDNF with HIIT (20). In addition, studies are needed to evaluate the effects of regular HIIT on BDNF and insulin sensitivity.

This study implemented a bodyweight-based HIIT protocol that did not rely on previous VO2-MAX data. This allowed for faster calculation of resistance when time does not permit VO2-MAX testing. This protocol also did not require subjects to endure a bout of continuous aerobic activity, which has been suggested to be poorly adhered to and unenjoyable for some individuals (44). The protocol led to an average RPE report of  $16.3 \pm 1.57$ , but was well endured by all subjects, as all were able to finish the protocol. This HIIT protocol could be employed as a training intervention or as part of a training intervention to investigate the effects of regular HIIT on cognitive performance. Further study regarding this HIIT protocol, including a greater number of subjects, increased number of training sessions, and additional physiological data collection such as heart rate, blood lactate, BDNF, insulin and performance measures are

encouraged to evaluate the potential of this resistance formula as a suitable alternative for VO2-MAX based prescription.

A more robust cognitive testing battery and larger sample sizes may also lead to stronger results.

This study demonstrated that a single bout of high intensity interval training is not sufficient to induce changes in cognitive performance as measured by the Montreal Cognitive Assessment 24 hours after exercise. This is most likely due to both an insufficient training volume and an insufficiently sensitive cognitive performance test. This study also demonstrated the need for further research into this relationship, with more robust testing protocols for physiological variables, such as insulin function, brain derived neurotrophic factor, insulin-like growth factors and leptin function as well as a larger cognitive performance testing battery which may include the Repeatable Battery Assessment Of Neuropsychological Status (RBANS) or the Wechsler Adult Intelligence Scale (WAIS).

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## **Appendices**

### **Extended Literature Review**

#### **Introduction**

Exercise and regular exercise training have a number of effects on the brain. Overall, long term aerobic and resistance training have shown promising results in the maintenance and improvement of cognitive performance in a variety of populations. These effects have been observed in large scale public health studies and have led scientists to become increasingly inclined to investigate this relationship in detail throughout the past two decades (Jedrziwski, Ewbank, Wang, & Trojanowski, 2010). The majority of studies have been performed with sustained moderate cardiorespiratory exercise. These studies have been fairly consistent in suggesting that a regular aerobic exercise training regimen can increase cognitive performance in some populations, and can delay or prevent cognitive decline with aging (Colcombe & Kramer, 2003). More recently, similar effects have been observed in resistance training (Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012).

The underlying mechanisms relating long term exercise training and cognitive performance are predominately physiology based. Brain derived neurotrophic factor (BDNF) is crucial to cognition and is modulated by exercise (Knaepen, Goekint, Heyman, & Meeusen, 2010). Conversely insulin resistance, which is often associated with a sedentary lifestyle, has been shown to correlate with atrophy in the hippocampus as well as reduced functional connectivity within the brain (Cherbuin, Sachdev, & Antsey, 2012; Musen et al., 2012). Interestingly, BDNF has been shown to increase insulin sensitivity (Marosi & Mattson, 2014).

The impact of single bouts of exercise on cognitive performance has also been documented in aerobic exercise, resistance exercise, and alternative exercise techniques such as yoga (Alves et al., 2012; Gothe, Pontifex, Hillman, & McAuley, 2013). The mechanisms driving the effects of acute exercise are distinct from those relating to regular exercise training. Typically, change in cognitive performance as a result of acute exercise is believed to be caused by primarily psychological mechanisms such as increased peripheral sensitivity to motor input, as well as increased sensitivity to sensory stimuli (Chang, Labban, Gapin, & Etnier, 2012). Other mechanisms are more physiology based, including increased total blood flow, increased epinephrine and norepinephrine levels and their effects on memory consolidation (Cahill & Alkire, 2003).

### **Mechanisms Associated With Cognitive Benefits from Exercise**

Ratey and Loehr (2011) recently categorized the proposed mechanisms responsible for short term cognitive changes from acute exercise. In their review, they suggested three categories of important mechanisms of action that acute exercise may have on cognitive performance. These mechanisms included psychological systems, molecular systems, and cellular systems. The psychological system mechanisms include attention, learning, and memory. The molecular systems include insulin function within the brain, catecholamines like epinephrine and norepinephrine, and neurotrophins like brain derived neurotrophic factor (BDNF). The cellular systems include changes to synaptic plasticity, neurogenesis, and angiogenesis (Ratey & Loehr, 2011).

Within the psychological systems, there is evidence to suggest that acute exercise changes an individual's strategy in decision making. The reticular-activating hypofrontality

model developed by Dietrich (2003) explains that during and immediately after exercise the reticular-activating system of the brain modulates activity and facilitates faster, more efficient information processing and hinders the actions of the prefrontal cortex. Together these effects will minimize time latency and explicit cognitive energy expenditure (Dietrich, 2003; Dietrich & Audiffren, 2011), which will increase efficiency of cognitive resource use and allow for greater priority to be placed on motor function in high stress situations as an evolutionary adaptation. These adaptations will, for the short term, decrease prefrontal-dependent cognition (Dietrich & Sparling, 2004). In their investigation, Dietrich and Sparling exercised a group of young males using either a cycling or running protocol designed to elicit a response of 80-90% of age-based maximum heart rate and sustain this level for 45 minutes. When compared to a control group who had not just endured a bout of exercise, the experimental condition displayed a deleterious effect on higher level thinking relative to their pre-exercise baseline. These results were not found in tests that ignored higher level thinking, lending support to the reticular-activating hypofrontality model (Dietrich & Sparling, 2004). One possible mechanism for this phenomenon is competition within the brain for oxygen and blood flow. During intense exercise, such as the 150% of VO<sub>2</sub>-MAX during interval training employed by Shibuya and colleagues, a decreased blood flow to the cerebral cortex was found (Shibuya, Tanaka, Kuboyama, & Ogaki, 2004). A decreased blood flow to the cerebral cortex was also found with intense isometric muscular contractions (Shibuya & Tachi, 2006). Decreased blood flow to the cerebral cortex may lead to unconscious strategizing towards minimizing effort.

In the molecular level mechanism, improved insulin sensitivity is a major outcome of high intensity interval training (Gibala & Little, 2010). A high normal fasting plasma glucose value, an indicator of potential insulin dysfunction, has been linked to atrophy in the

hippocampus and amygdala, and to neurodegeneration, seen as early as ages 60-64 (Cherbuin et al., 2012). Type 2 diabetics have been shown to have altered functional connectivity in their default mode network, as measured by functional magnetic resonance imaging (fMRI). This network includes the posterior cingulate cortex and is directly related to cognition (Musen et al., 2012). This decreased connectivity can be apparent via fMRI before any noticeable cognitive dysfunction or decrease in hippocampal volume (Musen et al., 2012).

Stress and arousal hormones are important effectors of memory consolidation and cognition (Cahill & Alkire, 2003). Cahill and Alkire (2003) investigated the injection of epinephrine into healthy young male adults. These authors found that an injection of epinephrine aided males in retrograde memory consolidation. Males who were provided information and then injected with epinephrine were later better able to recall this information when given a retention test. Given the impact that an acute bout of exercise has on increasing epinephrine levels (Ciolac et al., 2010), it is possible that the beneficial relationship between acute exercise and cognitive performance on tests that measure memory could be linked to the increase in epinephrine (Cahill & Alkire, 2003).

Brain derived neurotrophic factor (BDNF) is critical in the maintenance of neurosynapses and neuroplasticity, and its deficiency has led to insulin dysfunction and obesity in mice (Lyons et al., 1999; Rios et al., 2001). In humans studies, a BDNF deficient adolescent developed insulin and leptin resistance and his resulting body mass index (BMI) was 3.8 standard deviations above the age-related mean (Yeo et al., 2004). These authors suggested this was a result of his BDNF deficiency (Yeo et al., 2004).

Goda et al. (2013) investigated the effects of single bout of moderate intensity aerobic exercise on serum BDNF. These researchers found that about half of the subjects had a noticeable rise in serum BDNF post-exercise, yet when measured as a group, the changes were not significant (Goda et al., 2013). Ferris, Williams, and Shen (2007) found that exercise intensity was a modulator for changes in serum BDNF post exercise. These authors reported that either a VO2-MAX graded exercise test (GXT) or a 30 minute bout of exercise above the lactate threshold increased post-workout BDNF. In contrast, exercising 10% below the lactate threshold did not increase BDNF (Ferris et al., 2007). Because most high intensity interval training is done above the lactate threshold, researchers may expect to see similar post-exercise increases in BDNF with HIIT. While this effect appears to be short lived, regular exercise training may facilitate improvements in BDNF response to exercise (Berchtold, Chinn, Chou, Kesslak, & Cotman, 2005). Berchtold et al. (2005) reported that sedentary rodents which had been physical active previously were more sensitive to an exercise induced BDNF response when exercise was reintroduced compared to rodents that spent their entire lives sedentary. Individuals with disabilities that typically result in decreased BDNF may also have similar benefit from exercise (Castellano & White, 2008). Intense strength training has yielded promising results with regards to elevating serum BDNF levels (Knaepen et al., 2010).

Unlike long term regular exercise training, a single bout of exercise is unlikely to produce detectible structural changes in the central nervous system. The majority of physiological changes observed from a single bout of exercise are related to changes in peripheral blood flow that occur during and after exercise, which has been noted in our target action of high intensity interval training (Currie, McKelvie, & MacDonald, 2012).

When looking at long term exercise training, the underlying mechanisms for cognitive improvement represent more permanent changes. In mice studies, BDNF expression over time was elevated with exercise training. These results were typically maintained until cessation of the exercise protocol and for a few weeks of sedentary behavior (Adlard, Perreau, & Cotman, 2005). According to the authors, the changes were most notable in younger mice (Adlard et al., 2005). In rats, daily exercise had a protective effect on brain BDNF levels, even after some duration of sedentary behavior (Berchtold et al., 2005). The benefit of exercise on BDNF in rodents, however, diminishes over time (Berchtold, Castello, & Cotman, 2010). Individuals afflicted with Multiple Sclerosis tend to have lower serum BDNF compared to healthy controls (Castellano & White, 2008). In these individuals, exercise training results in a more pronounced increase in serum BDNF than individuals who do not have Multiple Sclerosis. This effect however appears to be transient, as BDNF was shown to increase after 4 weeks of exercise, but returned to baseline by week 8 of exercise. This transient effect could be explained by the aspect of novelty, as the challenge of learning a new exercise for someone with Multiple Sclerosis could demand neurological adaptation. Once that adaptation begins to diminish, BDNF may no longer have sufficient signaling to be elevated (Castellano & White, 2008).

Long term exercise training and fitness may also have an effect on brain structure. Using magnetic resonance imaging (MRI) and measuring the volume of the basal ganglia, Chaddock et al. (2010) found that pre-adolescent children with above average cardiorespiratory fitness had greater dorsal striatum volume, which is associated with executive function and motor control, compared to less fit children. Fit children also scored higher on cognitive performance tests, especially relating to attention (Chaddock et al., 2010). Exercise training has even been shown

in adults to prevent age-related atrophy in grey matter (Tamura, Nemoto, Arai, Matsuda, & Asada, 2012).



## **Cognitive Performance Outcomes from Exercise**

### **Aerobic Exercise and Training**

Aerobic exercise is a continuous locomotive movement sufficient to increase heart rate and oxygen consumption, usually sustained for thirty minutes or more (Ahlskog, Geda, Graff-Radford, & Petersen, 2011). The intensity of an aerobic exercise training program is usually measured in a percentage of VO<sub>2</sub>-MAX, age predicted heart rate max, or workload in watts (Ahlskog et al., 2011). In his 2010 review paper, Best explained how data suggests aerobic physical activity facilitates problem solving skills and executive function in children (Best, 2010). Aerobic activity is cognitively engaging, and leads children to unknowingly acquire motor skills and adopt strategies such as pacing. Aerobic physical activity that is organized as play also yields benefits from a socialization standpoint (Best, 2010). A positive relationship between exercise and cognition is seen in healthy populations as well as special populations, such as depressed individuals (Kharti et al., 2001). Improvements can be seen in the executive function of middle aged women after exercise bouts of either aerobic or resistance training (Alves et al., 2012).

Acute aerobic exercise also has direct cognitive consequences. When studying young men and women, cycling led subjects to alter only certain aspects of information processing via a cognitive performance test. For example, mean reaction time improved during exercise, but error rate was not affected (Arcelin, Delignieres, & Brisswalter, 1998). Reaction time improvements may be explained by increased sensitivity of the neuromuscular system to input and improved speeds of muscle contraction when selecting responses during exercise

(Davranche, Hall, & McMorris, 2009). This improvement, however, is still apparent when speed of the movement is taken out of the equation, because acute exercise improves premotor reaction time (Ozyemisci-Taskiran, Gunendi, Bolukbasi, & Beyazova, 2008). Generally, a moderate bout of aerobic exercise, such as 20 minutes of walking at 60% of the age-predicted heart rate reserve (HRR) does have a short term positive benefit on lower level information processing such as premotor reaction time. There is, however, little or no evidence to suggest a short term improvement on higher level thinking (Barella, Etnier, & Chang, 2010). While components like reaction time and other lower level processes are typically improved with an acute bout of aerobic training, higher level functions are typically left unchanged or even hindered, if the exercise is sufficiently intense (Dietrich & Sparling, 2004). In their meta-analysis, Chang et al. (2012) included 79 published articles; the subsequent data suggested that twenty minutes after cessation of exercise, overall cognitive performance was improved. Prior to that, and depending on intensity, performance may be hindered due to the physical recovery process (Chang et al., 2012). Because the majority of these effects subside soon after exercise is ceased, long term negative consequences of exercise on cognitive performance are unlikely.

When researching college aged men and women, Arcelin et al. (1998) tested students' reaction times before and during a bout of aerobic exercise. During exercise, reaction times were improved. The authors attributed this to late stage motor processes, which may be related to exercise based increases in arousal (Arcelin et al., 1998). These effects can also be seen in middle aged and older individuals (Barella et al., 2010). It is important to note that pre-motor reaction time and reaction time are distinct processes, as pre-motor reaction time excludes the time elapsed between the initiation of and completion of movement. Therefore, the

improvements to reaction time from exercise cannot be regarded as only a movement outcome (Botwinick & Thompson, 1966).

Acute bouts of intense aerobic exercise also impact the effort produced during cognitive tasks administered while exercising. Vigorous aerobic training of 35 minutes at 90% of the respiratory compensation threshold was more likely to cause individuals to cascade numbers in observable and obvious patterns when asked to list numbers randomly, instead of truly random listing, suggesting a more efficient and less effortful approach (Audiffren, Tomporowski, & Zagrodnik, 2009). There are physiological reasons that may explain the decrease in executive function seen in intense exercise. Bhambhani, Malik, and Mookerjee (2007) investigated the respiratory compensation threshold and cerebral oxygen concentrations associated with intense exercise. They found that once the respiratory compensation threshold was passed with intense exercise, concentration of oxygen in the cerebrum was hindered, due to competing resources partially from the primary motor cortex (Bhambhani et al., 2007). Due to the transient deleterious effect that very intense aerobic exercise has on oxygen concentration and blood flow to the cerebral cortex, scientists may expect a similar phenomenon to occur with high intensity interval training. These effects typically persist for less than an hour (Bhambhani et al., 2007).

Aerobic exercise that is sufficiently vigorous, with long enough interventions, has been shown in meta-analytic reviews to promote cognitive performance in older adults (Colcombe & Kramer, 2003). In school aged children, aerobic physical activity interventions have shown improvements on executive function, and children who engage in more physical activity are likely to have better school and cognitive performance (Best, 2010). Several studies have suggested that aerobic exercise training is effective at improving most aspects of cognitive

performance, however, data concerning the effects of aerobic exercise and working memory is inconsistent (Smith et al., 2010). Studies have also shown that aerobic exercise training helps to prevent gray matter atrophy (Tamura et al., 2012). Despite these known benefits associated with regular aerobic exercise training, most Americans do not adhere to exercise training guidelines (Bird & Hawley, 2012). The most commonly cited reason is lack of time. The current recommendation is 150 minutes a week (Bird & Hawley, 2012).

### **High Intensity Interval Training**

High intensity interval training (HIIT) is the act of completing repeated bursts of vigorous activity interspersed with periods of rest, active rest, or lighter activity (Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010). HIIT is often recommended as a lower time commitment, enjoyable alternative to continuous moderate aerobic activity. Despite a higher rating of perceived exertion recorded by their college aged participants, Bartlett et al. (2011) found using the physical activity enjoyment scale that HIIT, when performed with three minute intervals at 90% of VO<sub>2</sub>-MAX and three minutes of rest, was better enjoyed than a bout of continuous exercise at 70% of VO<sub>2</sub>-MAX for 50 minutes (Bartlett et al., 2011). The authors suggested that increasing exercise enjoyment will increase adherence (Bartlett et al., 2011). In their review, Bird and Hawley (2012) explained that due to lower time commitment, high intensity interval training may lead to greater exercise adherence than continuous aerobic exercise. Despite the name and higher typical ratings of perceived exertion, HIIT is well tolerated even amongst coronary heart disease patients (Guiraud et al., 2011).

High intensity interval training above the lactate threshold may increase BDNF, based on results from aerobic exercise studies conducted above the lactate threshold (Ferris et al., 2007).

High intensity interval training also causes a catecholamine response. Trapp, Chisholm, and Boutcher (2007) studied the effects of very short duration high intensity interval training, with bouts of 8-24 seconds in women. Subjects used 70% of their VO<sub>2</sub>-PEAK value during intense intervals, which were interspersed with intervals of 30 watts. This HIIT protocol caused an increased output of catecholamines epinephrine and norepinephrine (Trapp et al., 2007). Given the evidence suggesting that catecholamines are facilitative in the encoding of long term memories, these results gives promise to the notion of high intensity interval training as a method to improve some aspects of cognitive performance (Cahill & Alkire, 2003). Similar changes have been found using Wingate tests, a measure of anaerobic power and fatigue commonly used in exercise physiology labs, in college aged men and women (Vincent et al., 2004).

Repeated Wingate tests have been shown to significantly improve insulin sensitivity in young males as well (Babraj et al., 2009). In their investigation, as little as 250kcal of work was sufficient to improve insulin activity as measured with an oral glucose tolerance test. Subjects performed between four and six repeated Wingate tests with four minutes of rest in between efforts, and repeated this protocol six times over two weeks. While each session lasted only 17 to 26 minutes, the intervention was sufficient to improve insulin action (Babraj et al., 2009). Similar results have been found in interval training at 80-90% of VO<sub>2</sub>-MAX in college aged women. Insulin sensitivity scores improved to a greater degree than the group which completed a training regimen of continuous aerobic exercise (Ciolac et al., 2010). Other testing protocols that have been investigated suggested that both sprint interval and more aerobic interval training have elicited improved insulin sensitivity (Boutcher, 2010). Given the relationship between insulin resistance and cognitive dysfunctions, the hypothesis of a beneficial relationship between HIIT and cognition appears promising (Park, Lee, Chang, Kim, & Cho, 2009).

Based on the consistency of the positive literature to suggest aerobic exercise is beneficial to cognitive performance (Colcombe & Kramer, 2003), as well as the similar outcomes that HIIT produces on many physiological variables that have been shown to correlate with cognitive performance, there is foundation to hypothesize that high intensity interval training may have similar outcomes with cognitive performance (Babraj et al., 2009; Boutcher, 2010; Currie et al., 2012; Musa, Adeniran, Dikko, & Sayers, 2009; Talanian, Galloway, Heigenhauser, Bonen, & Spriet, 2006).

## Informed Consent

### **College of Health and Human Sciences**

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### **Department of health and Kinesiology**

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1. My name is David Young, I'm a graduate student at Georgia Southern University and I am doing this research to fulfill a graduation requirement, and explore the impact of a certain form of exercise on cognitive performance in healthy adults.
2. Purpose of the Study: The purpose of this research is to assess the impact of a single bout of interval training on cognitive performance with healthy adults in the southeast.
3. Procedures to be followed: Participation in this research will include completion of tests prior to the intervention which will assess physiological and cognitive status, an intervention, and post-intervention testing similar to the pre-intervention.
  - a. Pre-testing
    - i. Prior to testing you will be given the Par-Q, a form to determine if you are healthy enough to participate in an exercise study. You will be assessed for demographical information, training status, and body composition. You will also take a cognitive performance test.
  - b. Exercise Bout
    - i. You will perform an interval training bout on a stationary bike. This will include a general warm up, followed by 60s periods of effort followed by 60s periods of rest. The work periods will be performed at a resistance 85% of your maximum wattage output as estimated by your age. The rest periods you will pedal at 25 watts of resistance.
  - c. Post-testing
    - i. You will repeat the pre-testing procedures with different forms for the cognitive test.
4. Discomforts and Risks: Given the nature of exercise in an apparently healthy population, the chance of injury or complication exists. While interval training is

becoming more commonplace in recent years, the nature of interval training entails increased effort for shorter durations than regular aerobic exercise, this may lead to increased discomfort and feelings of exertion. In many sedentary individuals beginning an exercise program, a chance of minor muscular soreness, stiffness, or discomfort exists. During testing there is the chance of social discomfort during the body composition testing and cognitive tests.

5. "I understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators."
6. Benefits:
  - a. The benefits to participants include assessment of current cognitive performance as well as personal help in learning about and participating in a physical activity that is likely to improve your cognitive performance.
  - b. The benefits to society include an addition to the body of literature on the beneficial impact of exercise on cognitive function as well as some of the first literature related specifically to interval training.
7. Duration/Time required from the participant: The participant will be required to attend three sessions. The first session will include the subject data collection regarding demographics and training status, as well as body composition measures and the cognitive performance tests. The second session will be comprised of the interval training bout. In this session, you will be guided through a warm up, training session, and cool down based on your age-predicted maximum wattage output. The bout will consist of 5 intervals comprised of 60 seconds of effort against 85% of maximum wattage, interspersed with 60 seconds of active rest against 25 watts.
8. Statement of Confidentiality: Immediately upon the signing of informed consent, each subject will be given a numeric value for the duration of the study, and data will only be recorded in relationship to that numeric participant number. The primary investigator as well as the committee members will have access to the data associated with numbers for data collection and analysis purposes. Data will be stored in a locked filing cabinet in the primary investigator's office and upon his graduation will be given to the committee chair until it will be destroyed three years after the completion of the study.



9. Right to Ask Questions: Participants have the right to ask questions and have those questions answered. If you have questions about this study, please contact the researcher named above or the researcher's faculty advisor, whose contact information is located at the end of the informed consent. For questions concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-0843.
10. Compensation: Participants will receive no monetary compensation for participation in this research project
11. Voluntary Participation: If at any time the subject does not wish to continue on, they may discontinue participation in the study. If possible, please contact David Young so that the investigators are aware.
12. Penalty: There is no penalty for deciding not to participate in the study or for withdrawing at any time.
13. HIPAA: If the research falls under the HIPAA regulations, please go to the following site where additional information can be located on wording that will need to be included in the informed consent form: [HIPAAIC](#) **PLEASE NOTE: If your research project does not fall under the HIPAA regulations, please delete this statement (12).**
14. You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date below

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number H14113

Title of Project: Effects of a single bout of interval training on cognitive function in healthy adults

Principal Investigator:

David Young, 242 Highpoint Road Apt. H Statesboro, GA 30458

Other Investigator(s):

Jim McMillan [jmcmillan@georgiasouthern.edu](mailto:jmcmillan@georgiasouthern.edu)

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Faculty Advisor:

Jim McMillan [jmcmillan@georgiasouthern.edu](mailto:jmcmillan@georgiasouthern.edu)

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Participant Signature

---

Date

I, the undersigned, verify that the above informed consent procedure has been followed.

---

Investigator Signature

---

Date

**Subject Information Sheet****Student Information Sheet**

Subject Number: \_\_\_\_\_

Date: \_\_\_\_\_

- Age: \_\_\_\_\_
- Student Y/N: \_\_\_\_\_
  - If Y, Academic year: \_\_\_\_\_
- Have you ever been diagnosed with any psychological or neurological disorder? Y/N: \_\_\_\_\_
  - If Y, Diagnosis: \_\_\_\_\_

Gender	M	F
Height		
Weight		
SF 1		
SF 2		
SF 3		
SF Sum		

Training status (Years trained, description of training methods and goals):

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**Montreal Cognitive Assessment**

**MONTREAL COGNITIVE ASSESSMENT (MOCA)**  
 Version 7.1 Original Version

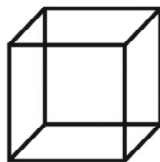
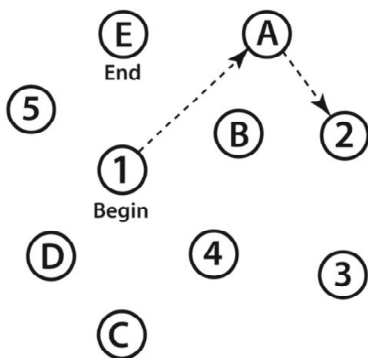
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Education :

Sex :

Date of birth :

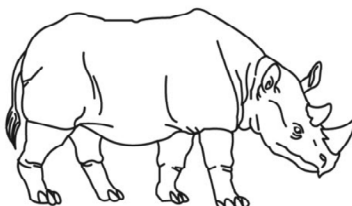
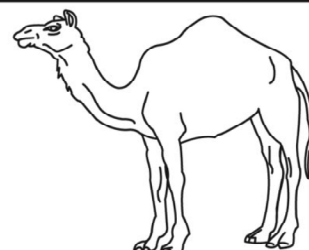
DATE :

**VISUOSPATIAL / EXECUTIVE**Copy  
cubeDraw CLOCK (Ten past eleven)  
(3 points)

POINTS

☐ ☐ ☐  
 Contour Numbers Hands

\_\_\_/5

**NAMING**☐☐☐

\_\_\_/3

**MEMORY**

Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No  
points**ATTENTION**

Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order

☐ 2 1 8 5 4

Subject has to repeat them in the backward order

☐ 7 4 2

\_\_\_/2

Read list of letters. The subject must tap with his hand at each letter A. No points if  $\geq 2$  errors☐ FBACMNAAJKLBAFAKDEAAAJAMOF AAB

\_\_\_/1

Serial 7 subtraction starting at 100

☐ 93☐ 86☐ 79☐ 72☐ 654 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

\_\_\_/3

**LANGUAGE**Repeat : I only know that John is the one to help today. ☐The cat always hid under the couch when dogs were in the room. ☐

\_\_\_/2

Fluency / Name maximum number of words in one minute that begin with the letter F

☐ \_\_\_\_\_ (N  $\geq$  11 words)

\_\_\_/1

**ABSTRACTION**

Similarity between e.g. banana - orange = fruit

☐ train - bicycle☐ watch - ruler

\_\_\_/2

**DELAYED RECALL**

Has to recall words

**WITH NO CUE**

FACE

☐

VELVET

☐

CHURCH

☐

DAISY

☐

RED

☐Points for  
UNCUED  
recall only

\_\_\_/5

**Optional**

Category cue

Multiple choice cue

**ORIENTATION**☐ Date☐ Month☐ Year☐ Day☐ Place☐ City

\_\_\_/6

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Normal  $\geq 26 / 30$ 

TOTAL

\_\_\_/30

Administered by: \_\_\_\_\_

Add 1 point if  $\leq 12$  yr edu

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1

## Montreal Cognitive Assessment (MoCA)

### Administration and Scoring Instructions

The Montreal Cognitive Assessment (MoCA) was designed as a rapid screening instrument for mild

cognitive dysfunction. It assesses different cognitive domains: attention and concentration, executive

functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. Time to administer the MoCA is approximately 10 minutes. The total possible score is 30

points; a score of 26 or above is considered normal.

#### 1. Alternating Trail Making:

Administration: The examiner instructs the subject: *"Please draw a line, going from a number to a letter in ascending order. Begin here [point to (1)] and draw a line from 1 then to A then to 2 and so on. End here [point to (E)]."*

Scoring: Allocate one point if the subject successfully draws the following pattern:

1 –A- 2- B- 3- C- 4- D- 5- E, without drawing any lines that cross. Any error that is not immediately self-corrected earns a score of 0.

#### 2. Visuoconstructional Skills (Cube):

Administration: The examiner gives the following instructions, pointing to the **cube**: *"Copy this drawing as accurately as you can, in the space below".*

Scoring: One point is allocated for a correctly executed drawing.

- Drawing must be three-dimensional
  - All lines are drawn
  - No line is added
  - Lines are relatively parallel and their length is similar (rectangular prisms are accepted)
- A point is not assigned if any of the above-criteria are not met.

#### 3. Visuoconstructional Skills (Clock):

Administration: Indicate the right third of the space and give the following instructions: *"Draw a clock. Put in all the numbers and set the time to 10 past 11".*

Scoring: One point is allocated for each of the following three criteria:

- Contour (1 pt.): the clock face must be a circle with only minor distortion acceptable (e.g., slight imperfection on closing the circle);
- Numbers (1 pt.): all clock numbers must be present with no additional numbers; numbers must be in the correct order and placed in the approximate quadrants on the clock face; Roman numerals are acceptable; numbers can be placed outside the circle contour;
- Hands (1 pt.): there must be two hands jointly indicating the correct time; the hour hand must be clearly shorter than the minute hand; hands must be centred within the clock face with their junction close to the clock centre.

A point is not assigned for a given element if any of the above-criteria are not met.

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#### 4. Naming:

Administration: Beginning on the left, point to each figure and say: *"Tell me the name of this animal".*

Scoring: One point each is given for the following responses: (1) lion (2) rhinoceros or rhino

(3) camel or dromedary.

### 5. Memory:

Administration: The examiner reads a list of 5 words at a rate of one per second, giving the following instructions: *"This is a memory test. I am going to read a list of words that you will have to remember now and later on. Listen carefully. When I am through, tell me as many words as you can remember. It doesn't matter in what order you say them"*. Mark a check in the allocated space for each word the subject produces on this first trial. When the subject indicates that (s)he has finished (has recalled all words), or can recall no more words, read the list a second time with the following instructions: *"I am going to read the same list for a second time. Try to remember and tell me as many words as you can, including words you said the first time."* Put a check in the allocated space for each word the subject recalls after the second trial.

At the end of the second trial, inform the subject that (s)he will be asked to recall these words again by saying, *"I will ask you to recall those words again at the end of the test."*

Scoring: No points are given for Trials One and Two.

### 6. Attention:

Forward Digit Span: Administration: Give the following instruction: *"I am going to say some numbers and when I am through, repeat them to me exactly as I said them"*. Read the five number sequence at a rate of one digit per second.

Backward Digit Span: Administration: Give the following instruction: *"Now I am going to say some more numbers, but when I am through you must repeat them to me in the backwards order."* Read the three number sequence at a rate of one digit per second.

Scoring: Allocate one point for each sequence correctly repeated, (N.B.: the correct response for

the backwards trial is 2-4-7).

Vigilance: Administration: The examiner reads the list of letters at a rate of one per second, after giving the following instruction: *"I am going to read a sequence of letters. Every time I say the letter A, tap your hand once. If I say a different letter, do not tap your hand"*.

Scoring: Give one point if there is zero to one errors (an error is a tap on a wrong letter or a failure to tap on letter A).

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Serial 7s: Administration: The examiner gives the following instruction: *"Now, I will ask you to count by subtracting seven from 100, and then, keep subtracting seven from your answer until I tell you to stop."* Give this instruction twice if necessary.

Scoring: This item is scored out of 3 points. Give no (0) points for no correct subtractions, 1 point for one correction subtraction, 2 points for two-to-three correct subtractions, and 3 points if the participant successfully makes four or five correct subtractions. Count each correct subtraction of 7 beginning at 100. Each subtraction is evaluated independently; that is, if the participant responds with an incorrect number but continues to correctly subtract 7 from it, give a point for each correct subtraction. For example, a participant may respond "92 – 85 – 78 – 71 – 64" where the "92" is incorrect, but all subsequent numbers are subtracted correctly. This is one error and the item would be given a score of 3.

### 7. Sentence repetition:

Administration: The examiner gives the following instructions: *"I am going to read you a sentence. Repeat it after me, exactly as I say it [pause]: I only know that John is the one to help today."* Following the response, say: *"Now I am going to read you another sentence."*

*Repeat it after me, exactly as I say it [pause]: **The cat always hid under the couch when dogs were in the room.***

Scoring: Allocate 1 point for each sentence correctly repeated. Repetition must be exact. Be alert for errors that are omissions (e.g., omitting "only", "always") and substitutions/additions (e.g., "John is the one who helped today;" substituting "hides" for "hid", altering plurals, etc.).

### **8. Verbal fluency:**

Administration: The examiner gives the following instruction: *"Tell me as many words as you can think of that begin with a certain letter of the alphabet that I will tell you in a moment. You can say any kind of word you want, except for proper nouns (like Bob or Boston), numbers, or words that begin with the same sound but have a different suffix, for example, love, lover, loving. I will tell you to stop after one minute. Are you ready? [Pause] Now, tell me as many words as you can think of that begin with the letter F. [time for 60 sec]. Stop."*

Scoring: Allocate one point if the subject generates 11 words or more in 60 sec. Record the subject's response in the bottom or side margins.

### **9. Abstraction:**

Administration: The examiner asks the subject to explain what each pair of words has in common, starting with the example: *"Tell me how an orange and a banana are alike"*. If the subject answers in a concrete manner, then say only one additional time: *"Tell me another way in which those items are alike"*. If the subject does not give the appropriate response (*fruit*), say, *"Yes, and they are also both fruit."* Do not give any additional instructions or clarification. After the practice trial, say: *"Now, tell me how a train and a bicycle are alike"*. Following the response, administer the second trial, saying: *"Now tell me how a ruler and a watch are alike"*. Do not give any additional instructions or prompts.

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Scoring: Only the last two item pairs are scored. Give 1 point to each item pair correctly answered. The following responses are acceptable:

Train-bicycle = means of transportation, means of travelling, you take trips in both;

Ruler-watch = measuring instruments, used to measure.

The following responses are **not** acceptable: Train-bicycle = they have wheels; Rulerwatch = they have numbers.

### **10. Delayed recall:**

Administration: The examiner gives the following instruction: *"I read some words to you earlier, which I asked you to remember. Tell me as many of those words as you can remember."* Make a check mark (  $\sqrt{\quad}$  ) for each of the words correctly recalled spontaneously without any cues, in the allocated space.

Scoring: **Allocate 1 point for each word recalled freely without any cues.**

### **Optional:**

Following the delayed free recall trial, prompt the subject with the semantic category cue provided below for any word not recalled. Make a check mark (  $\sqrt{\quad}$  ) in the allocated space if the

subject remembered the word with the help of a category or multiple-choice cue. Prompt all non-recalled words in this manner. If the subject does not recall the word after the category cue, give him/her a multiple choice trial, using the following example instruction, *"Which of the following words do you think it was, NOSE, FACE, or HAND?"*

Use the following category and/or multiple-choice cues for each word, when appropriate:

FACE: category cue: part of the body multiple choice: nose, face, hand



VELVET: category cue: type of fabric multiple choice: denim, cotton, velvet

CHURCH: category cue: type of building multiple choice: church, school, hospital

DAISY: category cue: type of flower multiple choice: rose, daisy, tulip

RED: category cue: a colour multiple choice: red, blue, green

Scoring: **No points are allocated for words recalled with a cue.** A cue is used for clinical information purposes only and can give the test interpreter additional information about the type of memory disorder. For memory deficits due to retrieval failures, performance can be improved with a cue. For memory deficits due to encoding failures, performance does not improve with a cue.

### **11. Orientation:**

Administration: The examiner gives the following instructions: "Tell me the date today". If the subject does not give a complete answer, then prompt accordingly by saying: *"Tell me the [year, month, exact date, and day of the week]."* Then say: *"Now, tell me the name of this place, and which city it is in."*

Scoring: Give one point for each item correctly answered. The subject must tell the exact date and the exact place (name of hospital, clinic, office). No points are allocated if subject makes an error of one day for the day and date.

**TOTAL SCORE:** Sum all subscores listed on the right-hand side. Add one point for an individual who has 12 years or fewer of formal education, for a possible maximum of 30 points. A final total score of 26 and above is considered normal.

## Par-Q

Physical Activity Readiness  
Questionnaire - PAR-Q  
(revised 2002)

# PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

If  
you  
answered

## YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

## NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

## DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

**PLEASE NOTE:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

**Informed Use of the PAR-Q:** The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.**

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME \_\_\_\_\_

SIGNATURE \_\_\_\_\_

SIGNATURE OF PARENT \_\_\_\_\_  
or GUARDIAN (for participants under the age of majority)

DATE \_\_\_\_\_

WITNESS \_\_\_\_\_

**Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.**



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